UNITED STATES DEPARTMENT OF AGRICULTURE

FOREST SERVICE

ADDITIONAL OBSERVATIONS OF THE 1932-33 MORTALITY OF FOREST INSECTS DUE TO FREEZING -NORTHEASTERN CALIFORNIA-

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Introduction:

It is an established fact that certain low temperatures which occur intermittently in the ponderosa pine region are responsible for a considerable reduction in the number of a given overwintering brood of Dendroctonus brevicomis. How often these low temperatures occur is problematical. Keen (3) has prepared a chart of minimum temperatures for the past two decades in Oregon. These temperatures indicate that local mortality may happen almost annually, however, widespread killing is much less frequent. Only once previous to the winter of 1932-33 has a definite record of western pine beetle kill due to freezing been recorded. This was in 1924 at Bend, Oregon where observations were made by Jaenicke. Mortality counts showed that over 50% mortality had occurred which was considered sufficient to abandon a control project which had been outlined for the following spring. The effects of the 1924 freeze were thought to be rather widespread although little is known except for the fact that very low temperatures were current throughout a wide area. During the winter of 1932-33 there was an additional record of mortality due to freezing. Observations have already been made on this freeze by Miller, Keen, Evenden, Salman and Beal.

Considerable time during the spring and summer of 1933 has been devoted to a detailed study of the results of this freeze. The following is a discussion of the findings of the study.

Methods of Study:

The observations may be divided into four groups: (1) amount of brood mortality immediately after the freeze, (2) amount of brood mortality in the spring of 1933, (3) determination of survival or brood potential in the spring of 1933 and (4) a study of brood development during the summer of 1933 in an attempt to determine the role of the freeze in the abundance of subsequent pine beetle population.

(1) During the winter a series of bark samples containing Dendroctonus brevicomis brood in the overwintering generation were shaved and counts made of all living and dead brood encountered. This served not only to determine the percent of mortality but to ascertain in what proportions the various stages overwintered. These samples were taken in the period, from the last of December to the first of March. The area sampled was in the northeastern part of California, covering the Modoc and parts of the Lassen, Shasta and Klamath national forests. These samples were obtained with the cooperation of the Forest Service, the McCloud Lumber Company, and the Weed Lumber Company. Figures ob-

tained from the Forest Service-Pickering Lumber Company control project in the Badger area of the Modoc also have been utilized.

(2) In June and July 1933 with the cooperation of the CCC organization, many winter brood trees were felled and analyzed to determine the percentage of brood mortality at different heights on infested trees. Representative trees were felled on sample plots located on the Modoc, Lassen and Shasta forests. The felled trees were also analyzed to show the distribution of insect species along the infested bole.

(3) A number of fine-mesh screen cages were placed on overwintering Dendroctonus brevicomis brood trees located in the vicinity of Badger township in the Modoc. The cages were placed five feet above the base and were for the purpose of determining the amount of emergence from certain selected winter brood trees. The trees were carefully chosen to contain as much living pine beetle brood as possible. The cages were placed in that area of the tree, near the base, where least mortality was known to have occurred.

(4) The cruising of regional survey plots was done with the aid of ECW funds and men, under the supervision of the Bureau of Entomology. Each plot was cruised twice or more during the season. Two selected plots in the Modoc were cruised at two week intervals throughout the summer. In this manner it was possible to follow rather closely the development of infestation as the summer progressed. The caging of summer brood trees was instrumental in rounding out this phase of the study. Past annual volume losses on survey plots were graphed to illustrate the effects of the freeze on the trend of the general infestation.

Observations made on the Modoc National Forest have been made a basis for this report. Certain data relative to the Lassen, Shasta and Klamath forests have been included to make the study more complete.

1932-WINTER BROOD CONDITIONS

General:

For a full understanding of the effects of the freeze, it is necessary to consider the brood conditions at the beginning of the winter of 1932. The general trend of insect infestation is also of importance in any attempt to calculate the direct effects of the freeze as reflected in volume losses. This particular point can much better be demonstrated several years hence when it will be possible to observe the subsequent trend of infestation.

Members of the California Regional Survey crews, who for the past several years have been making annual surveys of insect losses, noted last fall that the 1932 winter broods of the pine beetle were surprisingly heavy per unit of bark surface. This condition was noted particularly in the Modoc region. No population counts were made at the time. However, it is significant that these men, who have been examining broods in this same area for several years, should be impressed by the abundance of the overwintering progeny.

The plot losses for the Modoc (see Plate I, Fig. 1) show that the 1932 infestation killed the greatest volume since 1928. The extent of the losses in 1932 coupled with the fact that the plot figures showed the infestation to be an increasing one (1931 being higher than 1930 and 1932 in turn being higher than 1931) led to a winter control program in the Modoc during 1932. The spotting on this control area covered 21 sections with an average of 82.8 infested trees per section. Of the 21 sections 14 were treated before the project was closed down as a consequence of the freeze, Parker and Buck (7).

Thus as far as could be determined the prospect for 1933, exclusive of any control work, was an increase in an already epidemic condition. This then is a review of the conditions as outlined by Miller (6) and Salman (9).

Population, All Stages in Mid-winter:

In order to determine the extent and effectiveness of the freeze, members of the Bureau of Entomology shaved many samples during the winter. Aside from the percentage of dead and living beetles, several other interesting facts were discovered as a result of these counts.

A total of 393 individual samples equal to 90.1 sq. ft. were shaved from the Modoc, Lassen, Shasta and Klamath national forests. In all fifteen areas in these four forests were sampled. The average for these samples was found to be 280.3 individuals of all stages, per square foot. Keen (3) during the same period in southern Oregon found and average of 200 individuals per square foot. Keen's figures have a much larger basis and hence probably represent more nearly a general average. There is the possibility that in northern California the brood was greater per unit of area. In fact, there is considerable indication that it was higher (see the discussion of survival on individual trees from the Shasta). Following is a table containing a summary of the results of shaving 393 bark samples.

TABLE I
BARK COUNTS-CALIFORNIA REGION

	Locality	Nat. Forest	Date Collected	Date Counted	No. of samples	Area of Samples Sq. in.	Total Population: Total	Total Population: Dead	Total Population: % Mort.
1.	Badger	Modoc	Dec. 27-31	Dec. 31-Jan. 10	126	3524	6977	4507	64.6
2.	Cayton Valley	Shasta	Jan. 14	Jan. 18	15	465	1163	351	30.2
3.	White Horse	Modoc	Jan. 14	Jan. 18	17	703	1019	748	73.4
4.	Tionesta	Modoc	Jan. 17	Jan. 20-25	8	416	806	221	27.4
5.	Buck Creek	Modoc	Jan. 17	Jan. 20-25	29	892	2042	923	45.2
6.	Big Valley	Modoc	Jan. 17	Jan. 20-25	6	203	702	638	90.9
7.	Tionesta	Modoc	Jan. 19-21	Jan. 26	6	157	293	249	85.0
8.	Willard	Lassen	Feb. 8	Feb. 12	5	185	244	103	42.2
9.	Buck Creek	Modoc	Feb. 16	Feb. 20	18	694	1248	475	38.1
10.	Lava Beds	Klamath	Feb. 27	Feb. 29	10	526	809	614	75.9
11.	Horsethief	Klamath	Feb. 27	Mar. 4	10	616	1514	1266	83.6
12.	Butte Creek	Klamath	Feb. 27	Mar. 4	6	289	298	230	77.2
13.	Grass Lake	Klamath	Feb. 27	Mar. 4	9	417	538	392	72.9
14.	Wild Horse Mt.	Klamath	Feb. 27	Mar. 4	10	589	847	771	91.0
15.	Lassen National Forest		Mar. 8	Mar. 12-15	118	3299	6753	3081	45.6
					393	12,975 or 90.1 sq.ft.	25,253 or 280.3 sq.ft.	14,569	57.7

Distribution by Stages:

From the above samples it was possible to determine the percentage of the various stages during the winter months. Table II shows the relative abundance by stages as brought out by the shaved samples and by observations on 958 trees on the Badger control area.

TABLE II
Percent of Various Stages During the Winter Months-Dendroctonus brevicomis.

Date examined	Basis	Eggs	0-½ larvae	½-1 larvae	Pupae	New Adults
Nov. and Dec. 1932	958 trees, Badger control area	10.1	44.9	42.7	0.0	2.3
Dec. 1932 and Jan. 1933	393 samples, bark counts, four forests.	1.5	26.8	71.1	0.0 1 dead	0.6

There is considerable variation in the two records contained in Table II, both supposedly represent the same thing. It was chiefly for the purpose of showing this difference that the two sets of figures were included, since it is felt that the second is considerably the more accurate of the two. The first represents observations on 958 trees made under normal spotting conditions in the winter. The stages were recorded by each spotter as he made out a treating tag. By this method 87.6 percent of the total brood recorded was in the larval stage, about evenly distributed between small and large larvae.

The second set of figures represents counts made of all the brood contained in 393 samples sent to Berkeley from the previously mentioned fifteen areas. A microscope was used to count the eggs. Experienced men did all of the counting. There still remained the element of choice in recording large and small larvae, especially those about half grown. Under this set of conditions it was found that 97.9 percent represented the larval stage, with the large larvae in proportion of 2 to 1 as regards the small larvae.

From this it is immediately apparent that the reaction of the larval stage to cold is the important thing to consider, since other stages formed only a very small portion of the brood during the winter. It is not so apparent but there is good evidence that large larvae, being more numerous, are more of a consideration than small larvae.

CHARACTERISTICS OF THE INFESTATION

Plot Records:

Since it is known that low temperatures which are fatal to a portion of Dendroctonus brevicomis broods, occur from time to time in the ponderosa pine stands, it is reasonable to suppose that the effects of such freezes would be reflected in the amount of timber killed by this insect the following year. The pine beetle makes up a major portion of the ponderosa pine infestation, hence any noticeable increase or decrease in the numbers of this species should become apparent in the amount of infested timber. Plate I illustrates past, annual, volume losses of insect-killed timber on the Modoc, Lassen and Shasta survey plots. These have been placed on a per section basis. Referring again to the freeze reported in 1924 in Oregon, it is not certainly known whether the effects of this freeze extended into the Modoc area. What is known of the temperature conditions at the time makes it appear that such was the case. Plate I shows that the volume killed in 1925 on the Modoc was an increase over that in 1924. Keen (3) has shown by an analysis of the Oregon plots,

that a similar condition existed in that locality. The 1924 freeze presumably was not as severe as that in 1933. From this it seems that volume losses in the year following the freeze do not necessarily reflect the effects of brood mortality.

A study of the volume losses since 1924 on the Modoc does not determine definitely the state of the infestation at the time of the freeze in 1932. It is probable that it was in its ascendancy. This suggests a decrease in infestation following the freeze, which is just the reverse of what happened following the winter of 1924. The infestation on the Lassen seems to have been at its zenith in 1932. The data is insufficient for determination on the Shasta.

Plate II represents the 1932 infestation as being 100% for all insects. The volume killed in 1933 by the various insects has been compared to the infestation in 1932 on a percentage basis. The result shows that the total infestation in 1933 on all forests was approximately 50% of that in 1932. The Lassen showed a rather constant reduction of from 50 - 60% of all insects. On the Modoc pine beetle broods decreased 70% and others, including miscellaneous insects, were reduced 17%. Mixed broods increased 44%. On the Shasta Dendroctonus brevicomis was reduced 60% while mixed broods and others showed increases of 126% and 27% respectively.

Plate III in this series represents the percentage of the total volume loss, infested by the various insect species, comparing 1933 with 1932. The Lassen exhibits no appreciable difference. The Modoc distributes a decrease of 30% in Dendroctonus brevicomis, between mixed and others. The same is true of a decrease in 22% in the pine beetle on the Shasta.

The 1933 volume losses are in all cases estimates based upon cruises of permanent plots during September and October of 1933. The volumesobtained in these cruises have been multiplied by a correction factor for the particular date of cruise. Keen (2) has found over a period of years that certain percentages of total infestation are obtained when cruising plots during the late summer and early fall of the year in which infestation occurs.

Mr. F. W. Bacon, who is at the present time, January 1934, connected with a control project in the Badger area of the Modoc, reports in correspondence some interesting points concerning amount and composition of infestation. Apparently the 1933 season although starting with infestation at a low level, was one in which rapid increases occurred. Under these conditions use of Keen's correction factors for fall cruises would result in considerable underestimation of total

losses. Mr. Bacon states that the number of treated trees to date are in the following relationship: Dendroctonus brevicomis 32.4%, others 29.5% and mixed 38.1%. As yet no figures are available on volume losses.

The present Modoc control is being carried on in the fringe type of ponderosa pine stand in which concentration of insects other than the pine beetle is most marked. While this type is not representative of the entire Modoc stand it is likely to be indicative of trends throughout the stand. In other words, the estimated amount of 1933 infestation is probably low and further the increase in proportion of insect species other than Dendroctonus brevicomis may be more marked than has been indicated.

Stem Analyses of Individual Trees:

The above represents a summary of cruises. On the cruises the brood is sampled at the base and hence little can be known of what is above the base. During the past several seasons an attempt has been made to increase our knowledge of the "make-up" of an infestation. This has been done by felling sample trees and recording the insects found for the entire length of the stem. The analyses of a number of trees on a given area fall into several rather distinct groups of insect species. Each of these groups can be averaged to obtain an average tree for the group. This was done on the Badger control area during the winter of 1932. Forty-one trees are represented in Plate IV. Additional trees would add different small classes to the group but the predominance of Dendroctonus brevicomis as the most important insect would remain unchanged. A glance is sufficient to show the relative importance of the various insects. The pine beetle constitutes a major portion of the infested area of 40 trees. Buprestids are next being included in 14 trees.

Of six 1933 first generation Dendroctonus brevicomis-killed trees that were caged, all were stag-headed, large trees between 32 and 44 inches in diameter. Analyses of these trees showed that the pine beetle was either confined to the basal forty feet, usually less, or occupied only one side of the tree while other insects, mostly flatheads, infested the rest. Considerable difficulty was encountered in trying to locate any first generation trees so it is felt that those which were found were quite representative of the change of type of infestation following the winter of1932. It may be stated here that in 1930 in this same region the infestation was at a low ebb. During that season the few infested trees were large and decadent much as they were during the first of 1933.

Extensive cruising of plots in the Modoc showed that the first generation trees were very few in number. Pine beetle infestation was chiefly of the "fill-in" type usually attacking trees containing other insects. The cruises showed quite conclusively that the caged trees were representative of the type of infestation during the early summer of 1933.

EFFECTS OF THE FREEZE

Results of Winter Sampling:

The history of the early investigations of this freeze is included in the report by Salman (9). In that report were included the results of shaving 138 samples from the Badger control area. 133 of these yielded results which gave 64.4% kill of Dendroctonus brevicomis. In Table I, as a result of not including parent adults in the count, only 126 of these samples were totaled which changes the figure to 64.6% mortality.

Subsequent to the first lot of samples many more were shaved from the Modoc, Lassen, Shasta and Klamath forests. The results are shown in Table I. The average reduction for all areas was 57.7%. The Modoc and the Klamath were the center of greatest mortality to the pine beetle in California. The Lassen was next in severity of kill, while the Shasta showed the least kill of any area from which samples were sent to Berkeley. Observations in the field during the spring made it apparent that mortality on the Plumas was about the same as that on the Shasta. Apparently broods farther south than the Plumas were not affected by the freeze, at least not on the west side type. There is the probability that slight kill took place as far south as Lake Tahoe in the east side type. Plate XI shows the approximate area affected by the freeze.

Regarding the sampled areas; the Shasta exhibited in round numbers a kill of 30%, the Lassen 40-45% and the Modoc due to its size and diversity of conditions showed a variety of results, however, the Badger at 65% may be taken as being most representative. The Klamath averaged 80% reduction.

A study of the Modoc figures reveals considerable variation in mortality, one area from another. Different lots of samples from the same area also gave conflicting results. It is to be expected that there will be local variations in temperature over a large area such as the Modoc, due to differences in topography. These variations in temperature were reflected in differences in mortality.

The two sets of samples from the Tionesta tract on the Modoc vary from each other markedly. In cruising a permanent sample plot in this area in the spring it was noted that trees containing overwintering brood showed either nearly all of the brood living or nearly all dead (basal examinations). Evidently extremely local variations existed. The immediate proximity of the area to Glass Mountain may have accounted in some manner for the differences. A larger number of samples would probably have shown the average kill to fall about midway

between the two sets of samples.

Buck Creek is a unit in itself, being located in the Warner Mountains fairly well protected and for the most part having good air drainage. As a result two sets of samples from Buck Creek yielded considerably less mortality than did the Badger samples.

Distribution of Mortality to Pine Beetle Broods:

Two periods of intense cold were reported during the winter of 1932-33. The first of these, in December, was very widespread in effect causing mortality to bark beetle broods in Montana, throughout eastern Oregon and into northeastern California. The second period of cold occurred in February and was reported in Oregon as being shorter and more intense than that of December.

From the available information it seems that the February freeze in California was less severe than the one in December. No attempt has been made to separate the effects of the two periods of low temperature in California.

During the early spring of 1933 an attempt was made to determine the southwestern limits of mortality to pine beetle broods. A number of trees were examined along the road on the southern exposure of Mt. Burney in the Lassen. No kill was in evidence in this region. Just north of the crest of Burney trees were examined which showed 10-15% mortality by estimate. Proceeding north through the Shasta and Modoc forests the intensity of the kill increased. Individual trees exhibited considerable variation as was discovered throughout the study.

Buck Creek Observations:

As soon as it was possible to get into the forested areas in the spring, Bureau workers were sent to the Modoc to check the "follow-up" of freeze conditions. Activity of the beetle broods had not begun so there was ample opportunity to study development.

The first area to be visited was Buck Creek. This area was to be controlled so it was necessary to cruise a Bureau sample plot for the purpose of keeping the records in order. A rapid check up of the broods at the bases of infested trees was made to see if the samples shaved in the laboratory were representative of field conditions. The brood was about as expected with a slight additional mortality. It was decided to continue the project.

Part of the program was to make stem analyses of as many treated

trees on the plot as possible. As the stem analyses forms were filled out an estimate of the percentage of dead brood was noted. Kill was divided into four classes: 0-25, 25-50, 50-75, and 75-100, for ease in estimating. Almost immediately it was apparent that the living brood was confined chiefly to the basal 20-30 feet. Above this the mortality was complete in nearly all cases. The nearer the base the more living forms were encountered. In the vicinity of breast height the average mortality was about 50%.

Thus there was a considerably higher mortality than had been anticipated from the basal examinations. During the winter it had been suspected that there would be a difference in mortality between the base and higher on the tree. Salman (9) in his report covering the samples from the Badger control area states that no appreciable difference in mortality could be noted between samples taken at the base and those taken higher on the tree. However, the number of samples of this nature taken during the winter was very small. Keen (3) found very considerable differences in mortality at different heights on a tree.

The data collected at Buck Creek might be utilized to illustrate the degree of killing at the different heights on a tree. Since the observations were estimates rather than actual counts it was decided to use data collected in the Badger for this purpose. It is interesting to note that 100% mortality occurred in the upper portions of the tree at Buck Creek even though the freeze in this area was considerably less severe than that in Badger township.

Brood survival in individual trees:

During the spring and early summer of 1933 representative 1932 winter brood trees were felled on permanent sample plots on the Modoc. Samples were taken for the D. brevicomis infested length from the north and south sides of these trees; at the base, 5', 10' and every 10 foot interval thereafter. The samples were shaved and all living brood and emergence holes were recorded.

It was found that no appreciable difference in survival existed between the north and south sides, although there was a slight tendency for the south to be higher. The survival at the various heights was averaged and plotted as to north and south sides. The resulting points were interpolated to give the survival curve shown in Plate V. An explanation of this plate follows.

Keen (3) has found from a large number of counts in the past in this same general region, that the average emergence per square foot is 63 beetles. This figure has been plotted as a straight line above the survi-

val curve.

In 1923 Person (4) carried on experiments at Cascadel on the Sierra National Forest to determine the emergence of D. brevicomis at various heights on a tree. Nine square feet of infested bark taken at every 5' interval for the infested length of a single tree were caged separately and the emerging brood carefully recorded. The results were graphed on a square foot basis. The actual emergence was rather high. Person's graph has been superimposed upon Keen's average emergence figure. The result shows the tendency of emergence at various heights. It is admitted that the basis for this is rather insufficient but it is the best available data. A rather striking similarity may be noted between this curve and the survival curve. The rise in the survival curve between 30 and 60 feet was at first rather confusing, but Person's curve tends to indicate that the survival is directly proportional to abundance, with a certain variation at the base probably due to bark thickness.

Still refering to Plate V, the area ABCDE was taken as representing average emergence and the area ABE as the survival in the spring of 1933. ABE could not have increased in amount since it represents actual counts of all living form encountered in samples which were shaved after all egg laying had ceased. Undoubtedly some mortality would occur to the immature forms, which comprised 49.7% of the total, before emergence. Therefore, ABE represents maximum potential emergence of broods as sampled during the spring of 1933. The two areas were planimetered and ABE subtracted from ABCDE to obtain the amount of mortality. The mortality percent was then calculated and found to be 91.2%, average per square foot. The survival was 8.8%. It may be noted that above 70' no living brood was found thus giving 100% mortality for this portion of the stem.

Plate VI shows unrounded survival curves for the Lassen and Shasta National Forests. These were obtained in the same manner as the one from the Modoc.

There is a discrepancy in the mortality as calculated by the graphic method as outlined. This is due to the fact that the greater portion of the infested bark in any given tree must of necessity be on the lower portions of the stem because of the shape of the tree. Accordingly, those samples near the base where mortality was least should have the greater weight in averaging the amount of kill. Apparently it would be incorrect to figure the mortality from a straight line average emergence, see Person's curve. Yet this curve due to the limited basic data cannot be considered as being more than indicative of trends. Furthermore, this curve was figured on the basis of a

summer generation. It is entirely likely that the curve representing average emergence from overwintering trees would be quite different.

A number of 1933 summer generation trees were felled on the Lassen and Shasta forests and emergence counted, see Plate VII. The purpose of this was to augment Person's figures, however, more or less the same objections apply to the results.

Plate VIII represents mortality percent on the three forests. Curves 1-2-3 are compared with the 1933 average rounded emergence calculated from Plate VII. Curves 4-5-6 are compared with Person's normal emergence over Keen's average emergence, see Plate IV.

Considering first the Shasta, mortality percent compared with Person's curve shows no reduction, but rather a slight increase. However, it has already been pointed out that in the vicinity of 30% was known to occurred. A comparison with the 1933 emergence curve causes the mortality to become apparent. Apparently this is a better basis for comparison. Hence at least on the Shasta the average emergence figure is too low for the 1932 overwintering generation.

The Lassen shows a similar but smaller discrepency between the two but since the mortality was higher this would naturally follow.

The Modoc with its still higher mortality exhibits a striking similarity between the two curves. Thus it would seem that curves 1-2-3 on Plate VIII show as nearly as possible the mortality on the three forests due to last winter's freeze.

Effects of Bark Thickness on Mortality:

It is pertinent at this point to mention the effect of bark thickness on mortality percent. Salman (9) and Keen (3) have found that the mortality varies inversely as the thickness of the bark, see Plate IX. This would be expected due to the insulating qualities of bark. In the field it was repeatedly noted that trees having to all outward appearances the same qualities as to bark thickness, site, vigor and the like, would exhibit entirely different degrees of mortality. In fact, it will be noted from Plate IX, fig. 2, that there is no well defined mode of samples. This may in many cases be due to the impossibility of determining accurately the thickness of bark over the brood in a given tree. It has been observed that in trees with very thick bark, often deeply ridged, that the brood tends to become localized in the vicinity of the crevices, thus tending to lessen the effective protective layer. Thus it is conceivable that a tree of uniform bark thickness might protect the brood to a greater extent than

a tree with deeply ridged bark but of much greeter everage thickness. In addition trees with the same thickness of bark may have different quality of bark (not measurable) or the brood may be differently located in relation to the outer bark surface.

In shaving up the many bark samples it was repeatedly noticed of individuals side and side in the bark, that one would be dead and the other living. This must be attributed directly to individual differences in ability to resist cold. This difference in individual resistance is apparent in laboratory tests in which temperature is reduced to a point where all beetles succumb due to cold. Mortality of all the individuals does not take place at a certain degree but is spread over a number of degrees.

Summing up this discussion it may be stated that bark thickness is a direct and positive protection for broods against freezing. The relative protective influence of different bark thicknesses can be approximated over a large number of samples. There will always be many cases which fall out of line due to variations which are difficult or impossible to measure. By this it is meant to emphasize the importance of taking sufficient samples in cases concerning mortality from freezing.

Mortality to Different Stages:

From the above it would naturally follow that insects in the inner bark would receive greater protection than those nearer the outer surface. There is the question of moisture in the inner bark to be considered. Miller (5) and Beal (1) have found that the presence of moisture tends to lessen the resistance of D. brevicomis to low temperatures. Accordingly, these two factors, bark thickness and the presence of moisture, act in opposition to each other. Keen (3) has shown a 130% increase in mortality of small larvae over all larvae. Table III shows an increase of only 2.3% in the northern California area. During the winter it was found that the egg stages suffered the least mortality.

Brood work in the early spring showed living eggs and small larvae were much more abundant in relation to the total living population than their numbers in the original overwintering population would allow unless mortality in those two stages of the insect had been considerably less than in the other stages. In addition many eggs were found that, as the season developed, did not hatch and the population of small larvae in the brood trees became smaller and smaller as they continued to die off. Thus a gradual and progressive mortality in the egg and small larval stages was observed in the spring work and must have been occurring since the time of the freeze. The best evidence seen that would substantiate this point is that numerous dead young larvae were found in the bark at the time of the first examinations in the spring that had not been dead for any great length of time. The decomposition of such specimens, although apparently of the same

type as that found in the winter freeze mortality counts, had not advanced to the point to which those individuals unquestionably killed by the freeze had reached. It is not known whether the supplementary mortality was due to other causes such as changes in food conditions, or development of bacteria or fungi. It is logical to expect that this mortality is not due to the freeze and may be more normal than otherwise. Certainly small larvae which overwinter in the cambium region are not confronted by the same conditions in the spring that they would meet if continually active in a dying tree as in the summer time. It may be that food conditions change more rapidly than the larvae are able to develop during the winter so that, on resumption of activity, they meet food unsuited for their use and do not survive.

TABLE III

Comparison of Mortality of Small Larvae to Mortality of All Larvae - Northern California

Locality	All Larvae			Small Larvae			Increase in Mortality
	Dead	Total	% Mort	Dead	Total	% Mort	
Badger	256	376	68.1	117	218	53.7	-21.2
Cayton Valley	145	455	31.9	76	186	40.9	+28.2
White Horse	179	247	72.5	67	93	72.0	- 0.8
Tionesta	210	704	30.0	78	231	33.8	+12.7
Buck Creek	878	1994	44.1	309	657	47.0	+ 6.6
Big Valley	635	697	91.1	317	350	90.5	- 0.7
Tionesta	193	224	86.2	107	115	93.1	+ 8.0
North Warners	393	1097	35.7	84	200	42.0	+17.7
Buck Creek	91	232	39.2	12	37	32.4	-17.4
Lava Beds	457	553	82.7	75	90	83.4	+ 1.8
Horsethief	953	1202	79.3	300	432	69.5	-12.4
Butte Creek	85	142	59.9	18	35	51.4	-14.2
Grass Lake	247	314	78.7	60	66	90.9	+15.5
Wild Horse Mt.	629	745	84.5	104	131	79.5	- 5.9
Lassen Nat. For.	1894	4176	45.4	753	1415	53.2	+17.2

Reference to Table I shows that in the samples shaved only one pupa was found. This had been killed by the cold. Evidently only a very few *D. brevicomis* pass the winter in the pupal stage. This has been noted

a number of times previously by various Bureau workers.

In attempting to locate brood trees containing living new adults in the early spring no success was achieved. This portion of the brood, although small in amount, didnnot pass the winter successfully.

As a result the overwintering large larvae were the ones to initiate the first 1933 generation. The outcome of this was that emergence of the overwintering generation took place later and did not extend as far into the summer as usual. The peak of emergence probably remained but little changed due to the fact that the large larvae normally produce this portion of the emergence.

Emergence of the 1932 Overwintering Generation:

Early in the spring a number of 1932 winter trees were located at Hackamore in the Modoc. These trees were chosen as containing the most living brood of any trees on the area. Cages were placed on these trees about 5' above the base and extending upward to about 9'. The bark area covered by each cage was about 5 square feet. In all but one case the cages were placed on the south side of trees. One exception was a tree on which two cages were placed, one on the north and one on the south. Emergence from these cages was counted at two day intervals. Plate X shows the emergence expressed in percent, from twelve of these cages.

The emergence from the twelve cages was considerable, an average of 92.5 adults per square foot from a total of 66.3 square feet. This demonstrates quite conclusively that although the average mortality was very high, here and there throughout the area were trees in the bases of which a considerable nucleus of living beetles still persisted. Under favorable conditions this nucleus could very rapidly build up to epidemic proportions.

This seemed to be the case during the summer of 1933. The first generation trees were few in number, large and usually decadent mixed brood trees. The second generation came in much stronger with more typical and smaller trees being attacked.

Effects of the Freeze on Other Insects:

Little can be added to the observations made by Salman (9). The cerambycids in general were affected about as were the pine beetle, very few survived in the upper portions of the trees while a considerable number overwintered successfully in the bases of trees. The buprestids suf-

fered less mortality than did the D. brevicomis. It has been stated from bark counts that the predators were killed in greater proportions than were the pine beetle broods. Person (8) has shown that from 40-90% of Enoclerus lecontei larvae migrate to the base of the infested tree before pupating. Some pupate in the duff, others under the thick bark at the base. In these locations the clerids would be well protected and little likely to be killed by freezing. The samples that were counted during the winter undoubtedly contained only those clerids which normally remain behind. The mortality among these was heavier than among the pine beetle brood.

During the spring when the first generation 1933 trees appeared great numbers of E. lecontei adults could be seen running over them. The clerids were in such great numbers that it was thought at the time that they would reduce the D. brevicomis population still farther. As the summer progressed it became apparent that even the combination of heavy freeze mortality and an abundance of clerids was not sufficient to check the infestation for long.

Temnochila virescens var. is not as important an enemy of the pine beetle as is E. lecontei, Person (8). This insect does not migrate to the extent that the clerid does and hence suffered high mortality. Few adults were noted in the spring of 1933.

SUMMARY

During the winter of 1932-33 widespread killing of the western pine beetle was observed throughout the ponderosa pine belt. During the winter many bark samples, taken from areas in Northern California, were shaved to determine the amount of mortality. During the following spring additional studies were made with the aid of the CCC organization. Cruises were made, trees felled and analyzed, and other trees were caged in an attempt to determine the effects of the freeze.

From regional survey data it was apparent that the 1932 winter generation was in an epidemic status. Broods were observed to be heavy.

A summary of 393 samples showed an average of 280.3 individuals per square foot of all stages in midwinter. This figure is rather higher than average.

97.9% of the overwintering brood was in the larval stage with large larvae twice as numerous as small larvae. Field observations of abundance of stages was found to be only approximate.

Total insect losses in years following mortality due to freezing are variable. In 1925 losses increased while in 1933 they decreased.

Comparison of the effects of the freeze on different forests is difficult to make because the status of infestation at the time of the freeze varied. On the Modoc, Lassen and Shasta forests total infestation dropped about 50% in 1933. D. brevicomis was reduced 70% on the Modoc, 60% on the Shasta and 50% on the Lassen. Reductions of pine beetle broods on the Lassen and Shasta do not conform to the relative amounts of mortality on these forests.

By expressing D. brevicomis in terms of composition by insect species, it was found that the Lassen remained constant in 1932 and 1933. The Modoc showed a decrease of 30% in the D. brevicomis and the Shasta a decrease of 22% for the same species.

Recent observations in the Modoc make it appear that estimates of 1933 losses are low. Also there is indication that insects other than the pine beetle have increased in importance considerably more than was expected.

Stem analyses of representative trees show unquestionably the predominance of D. brevicomis in the infestation during the winter of 1932. Treesanalyzed in the spring exhibited the tendency of other in-

sects to become of relatively more importance.

Bark samples from fifteen areas gave mortality of pine beetle broods of 30% on the Shasta, 40-45% on the Lassen, 65% on the Modoc and 80% on the Klamath National Forests. Spring observations indicated that the freeze on the Plumas was about the same as that on the Shasta. Little if any mortality occurred farther south than the Plumas.

Considerable variation in mortality was noted in different areas on the Modoc due to differences in topography. The Buck Creek control project was carried out despite the fact that stem analyses of infested trees showed that more mortality had occurred than basal examinations had indicated.

Many 1932 winter brood trees were felled on the Modoc, Lassen and Shasta to determine the percentage of mortality along the bole. A comparison of the mortality from these trees checked rather closely with results which had been obtained from winter bark counts. Considerable discussion of this phase of the study necessitates a reference to the figures mentioned in the text.

The statement that mortality due to freezing varies inversely as the thickness of the protecting layer of bark has been rechecked.

The study indicates that mortality immediately following the freeze was about the same in the large and the small larval stages. Eggs were the least affected. During the spring of 1933 both the eggs and the small larvae died in large numbers so that few adults developed from forms which overwintered in these stages.

Emergence of the overwintering generation, considerably reduced in amount, reached its peak as in normal seasons, during the first of June. Both early and late emergence of the winter brood were very limited.

Cerambycids reacted to the low temperatures about as did the pine beetle broods. Enoclerus lecontei due to its habit of migrating to the base of infested trees, passed the winter without much mortality other than to those which did not migrate. Those clerids which remained in the upper portions of the trunk were killed in greater proportion than the pine beetle. Buprestids in general were affected less than D. brevicomis. Temnochila virescens mortality was relatively high.

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(3) Keen, F. P. and Beal, J. A. Low Temperatures as a Limiting Factor in Western Pine Beetle Epidemics. Progress Report No. 1, April, 1933-Portland.

(4) Miller, J. M. and Person, H. L. A Quantitative study of Dendroctonus brevicomis Broods, their Mortality, the Effect of Predators and Emergence Periods for Dendroctonus brevicomis and Thanisimus nigriventris-April,1924-Northfork.

(5) Miller, J. M. High and Low Lethal Temperatures for the Western Pine Beetle. Journ. Agr. Res., 43,4: 303-321-1931.

(6) Miller, J. M. A Record of Winter Kill of Western Pine Beetle in California 1932. Journ. of For. Vol. XXXI, No. 4, 1933.

(7) Parker, A. L. and Buck, E. Report Badger Unit Insect Control Project, 1932-33. Forest Service, Modoc.

(8) Person, H. L. A Study of the Clerid Enoclerus lecontei Wolc. as a Factor in the Control of the Western Pine Bark Beetle. April, 1930 - Berkeley.

(9) Salman, K. A. Field Observations on Mortality of Western Pine Beetle due to Freezing. Jan. 12, 1933-Berkeley.

PLATE I

AVERAGE PLOT LOSSES - PER SECTION BASIS

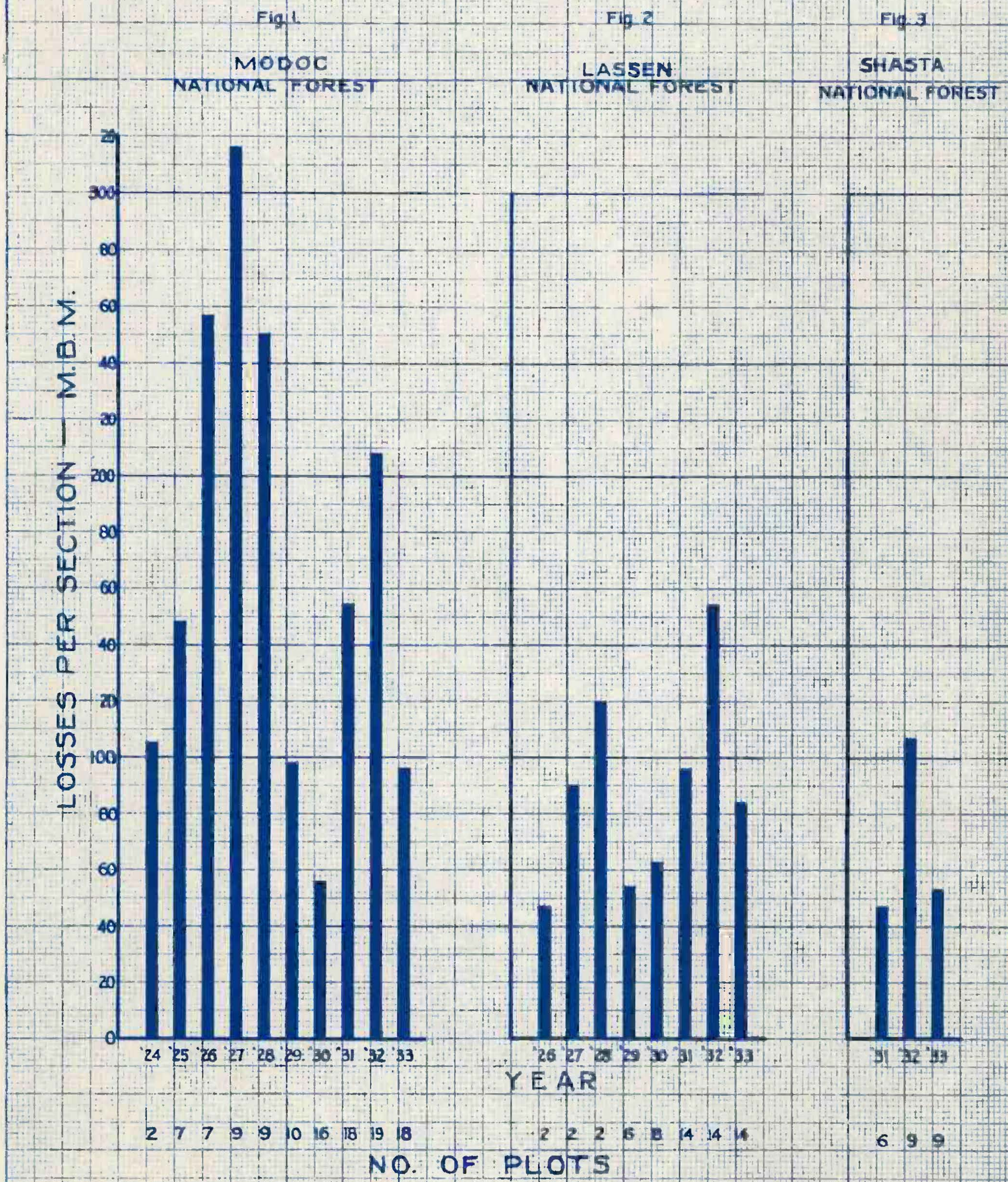
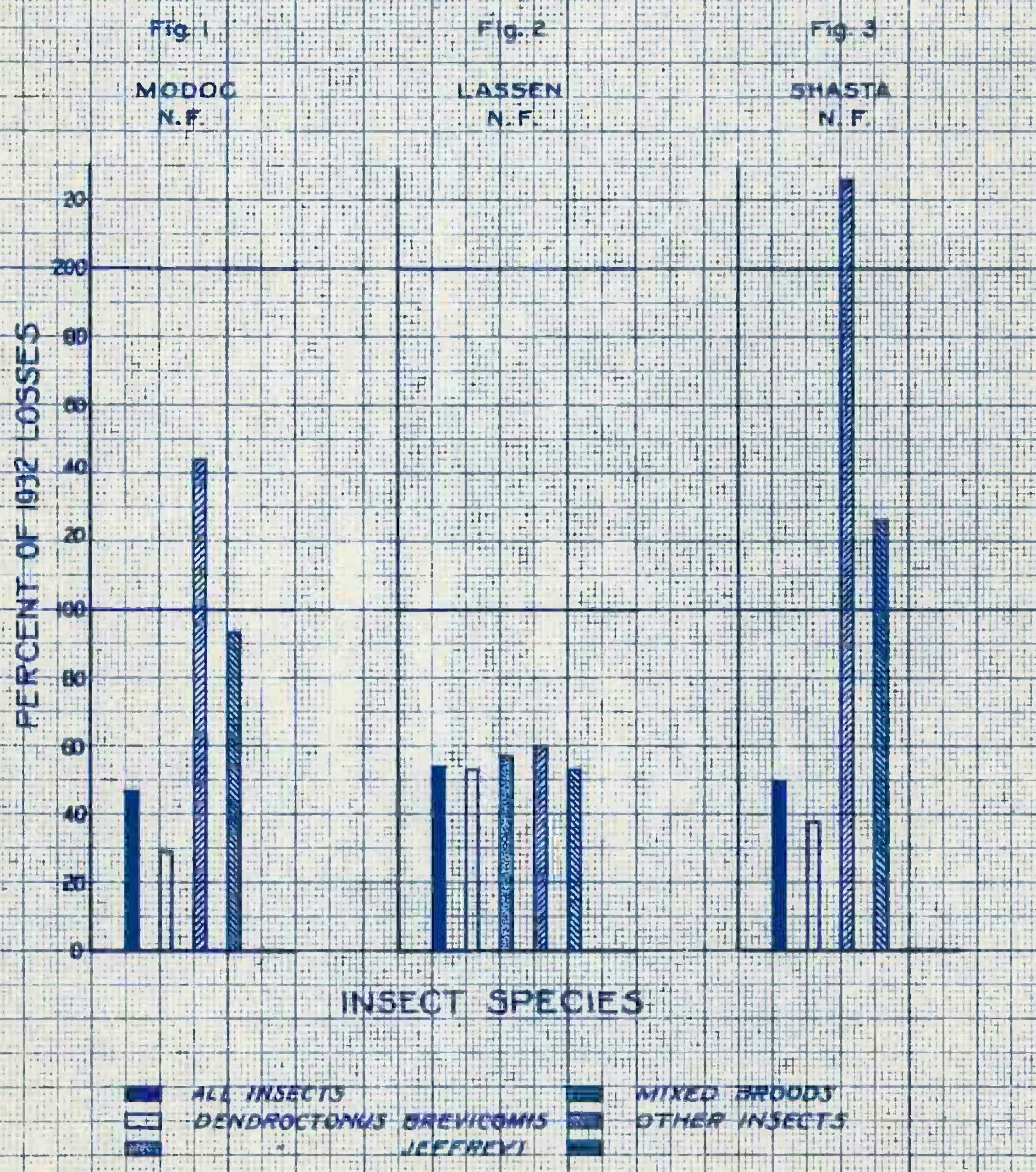


PLATE II

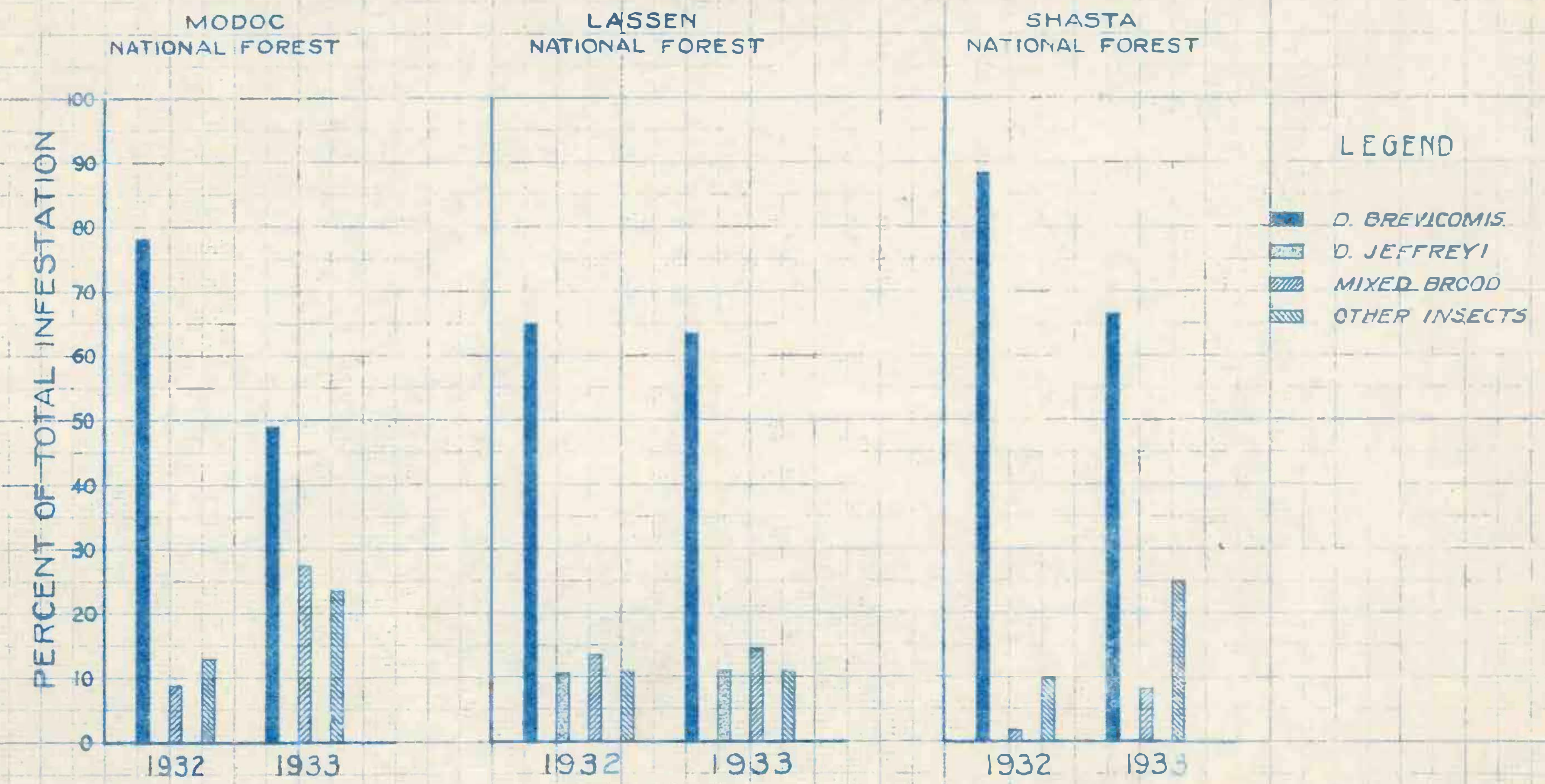
1933 INFESTATION IN RELATION TO 1932 LOSSES



K & E CO., N. Y.

PLATE III

COMPOSITION OF INFESTATION - BY SPECIES, 1932-1933



Basis: AVERAGE OF 18 320-AC. PLOTS | AVERAGE OF 14 320-AC. PLOTS | AVERAGE OF 9 320-AC. PLOTS

PLATE IV

INFESTATION TYPES — PONDEROSA PINE

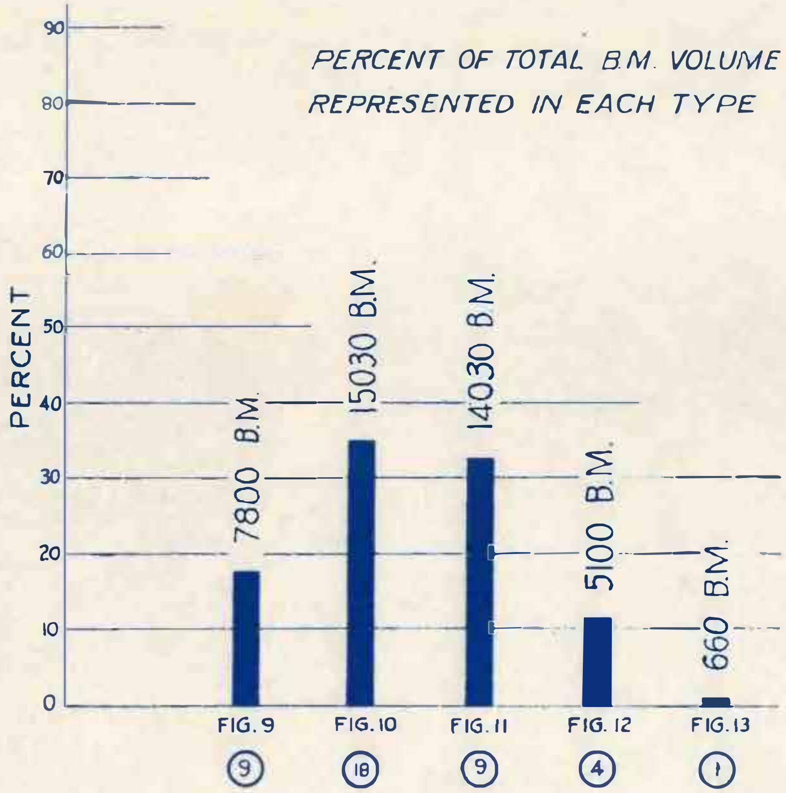
BADGER CONTROL AREA

MODOC NATIONAL FOREST, CALIFORNIA

OVERWINTERING 1932-1933 BROOD TREES

SCALE

HORIZONTAL 0.2" = 5"
VERTICAL 0.2" = 5'



LEGEND

- *DENDROCTONUS BREVICOMIS* (D.B.)
- *MELANOPHILA SPP.* (F.H.)
- *DENDROCTONUS MONTICOLAE* (D.M.)
- *GREEN*
- *NO. OF TREES IN EACH TYPE*

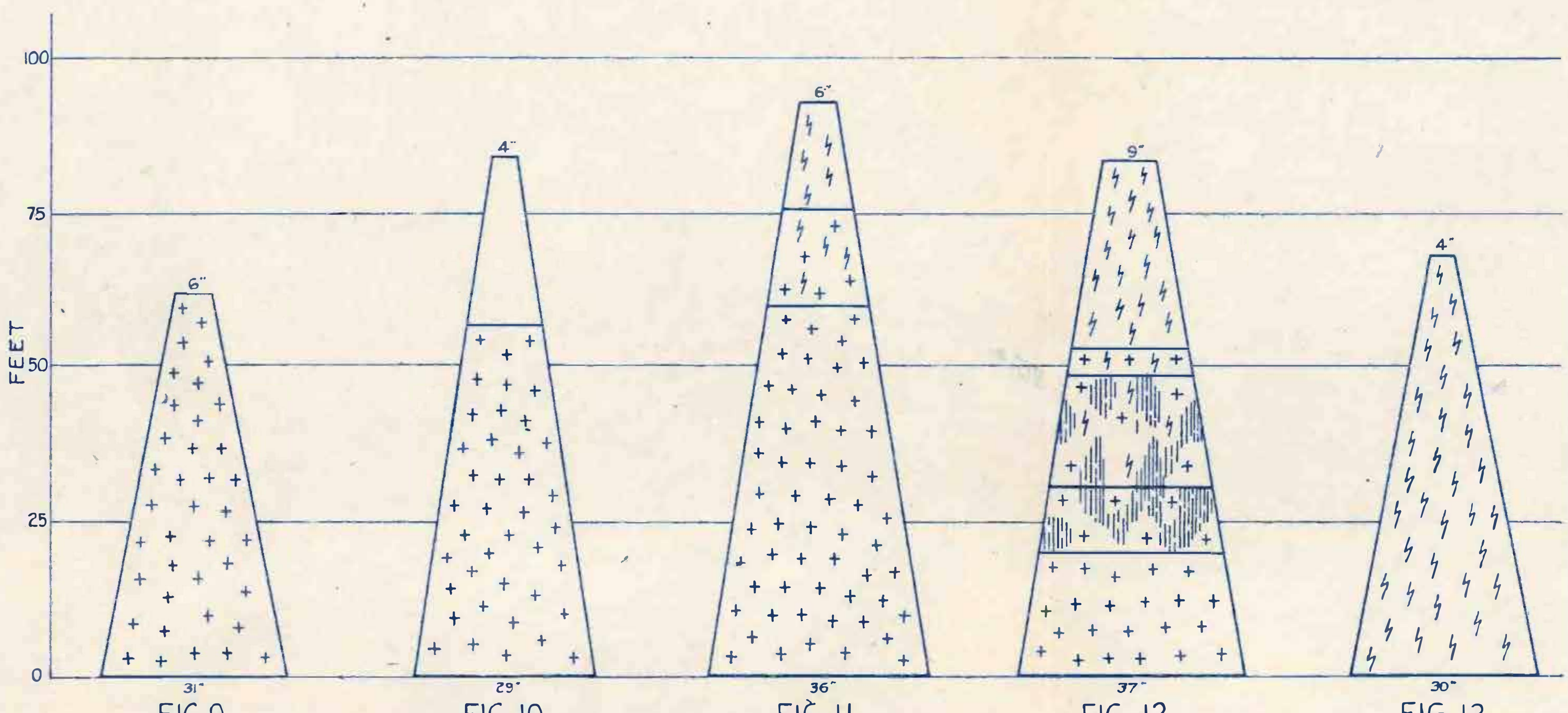


FIG. 9
D.B.

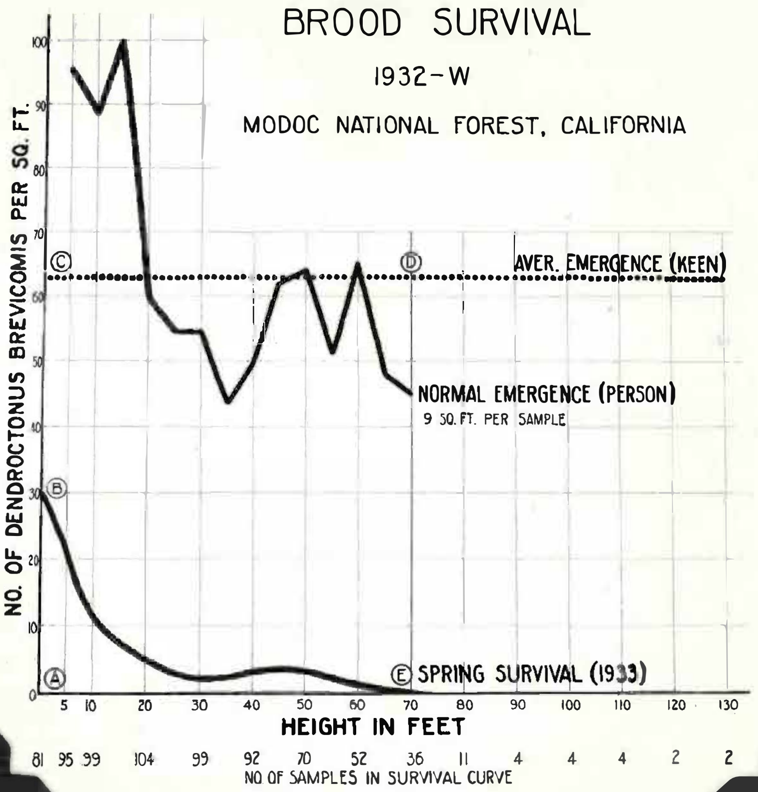
FIG. 10
D.B.-GREEN

FIG. 11
D.B.-F.H.

FIG. 12
D.B.-D.M.-F.H.

FIG. 13
F.H.

PLATE V



BROOD SURVIVAL
1932-W
MODOC NATIONAL FOREST, CALIFORNIA
NO. OF DENDROCTONUS BREVICOMIS PER SQ. FT.
AVER. EMERGENCE (KEEN)
NORMAL EMERGENCE (PERSON)
9 SQ. FT. PER SAMPLE
SPRING SURVIVAL (1933)
HEIGHT IN FEET
81 95 99 104 99 92 70 52 36 11 4 4 4 2 2
NO OF SAMPLES IN SURVIVAL CURVE

PLATE VI

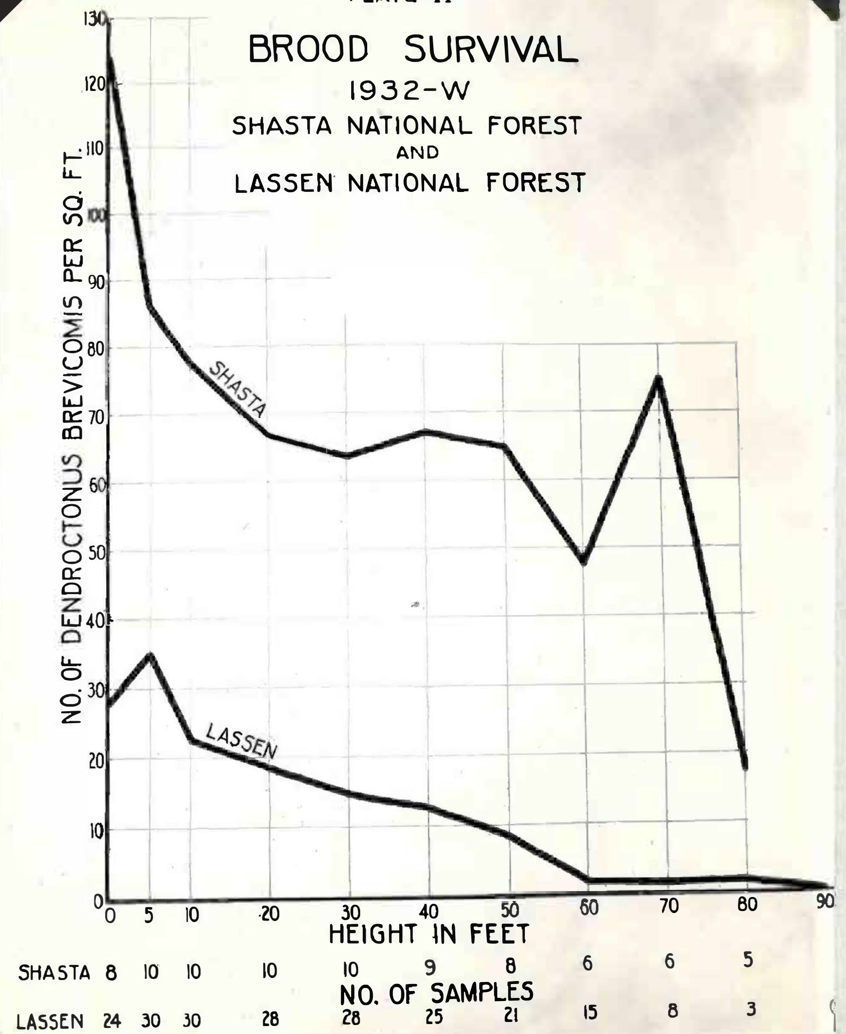
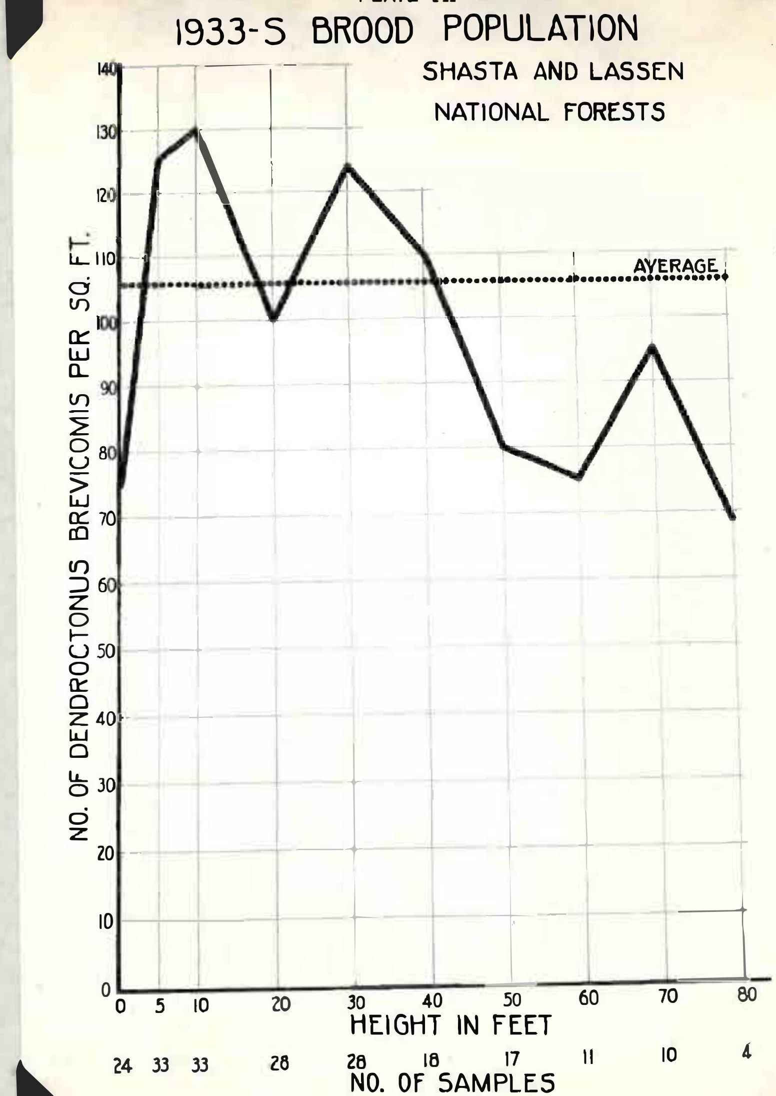

BROOD SURVIVAL
1932-W
SHASTA NATIONAL FOREST
AND
LASSEN NATIONAL FOREST
NO. OF DENDROCTONUS BREVICOMIS PER SQ. FT.
130
120
110
100
90
80
70
60
50
40
30
20
10
0
SHASTA
LASSEN
0 5 10 20 30 40 50 60 70 80 90
HEIGHT IN FEET
SHASTA 8 10 10 10 10 9 8 6 6 5
NO. OF SAMPLES
LASSEN 24 30 30 28 28 25 21 15 8 3

PLATE VII



1933-S BROOD POPULATION
SHASTA AND LASSEN
NATIONAL FORESTS
AVERAGE
NO. OF DENDROCTONUS BREVICOMIS PER SQ. FT.
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
0 5 10 20 30 40 50 60 70 80
HEIGHT IN FEET
24 33 33 28 28 18 17 11 10 4
NO. OF SAMPLES

PLATE VIII

MORTALITY PERCENT

ON THE MODOC, LASSEN, & SHASTA NATIONAL FORESTS

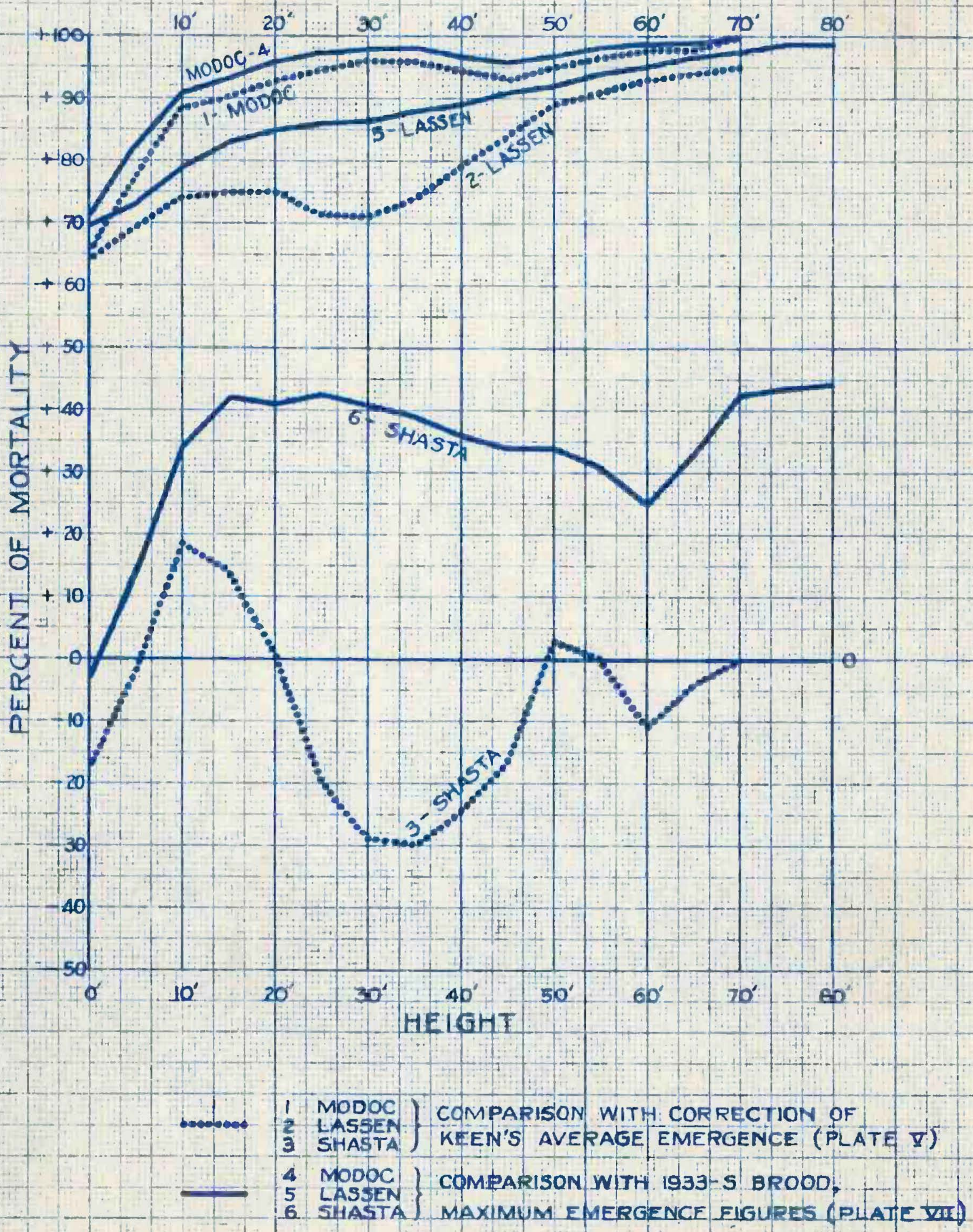
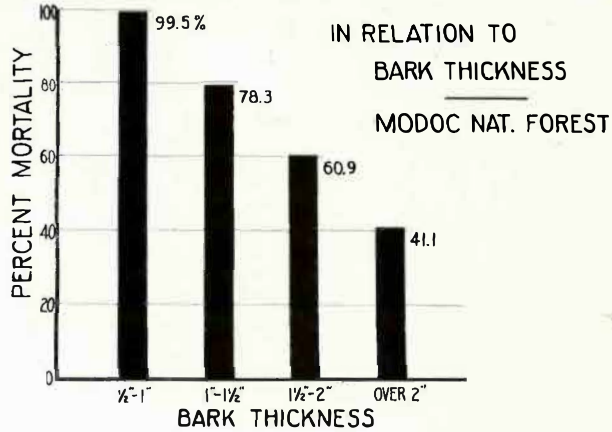


PLATE IX

AVERAGE MORTALITY PERCENT

Fig. 1



DISTRIBUTION OF SAMPLES
IN BARK THICKNESS CLASSES

Fig. 2

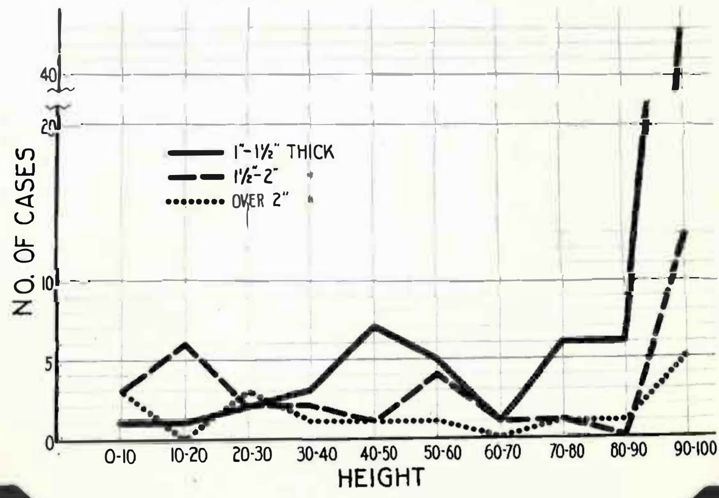


PLATE X

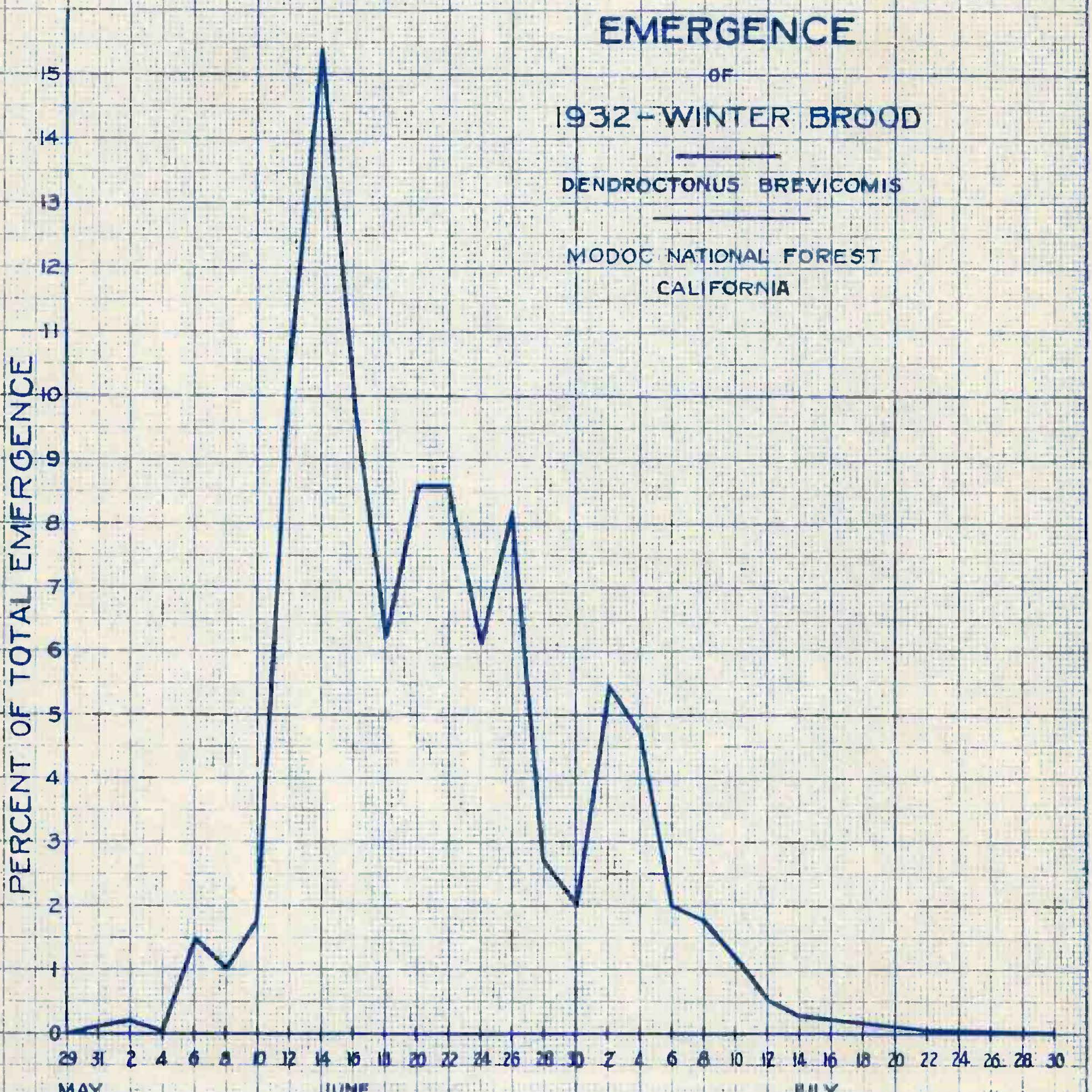
EMERGENCE

OF

1932 – WINTER BROOD

DENDROCTONUS BREVICOMIS

MODOC NATIONAL FOREST
CALIFORNIA



Basis :— 12 Tree Cages

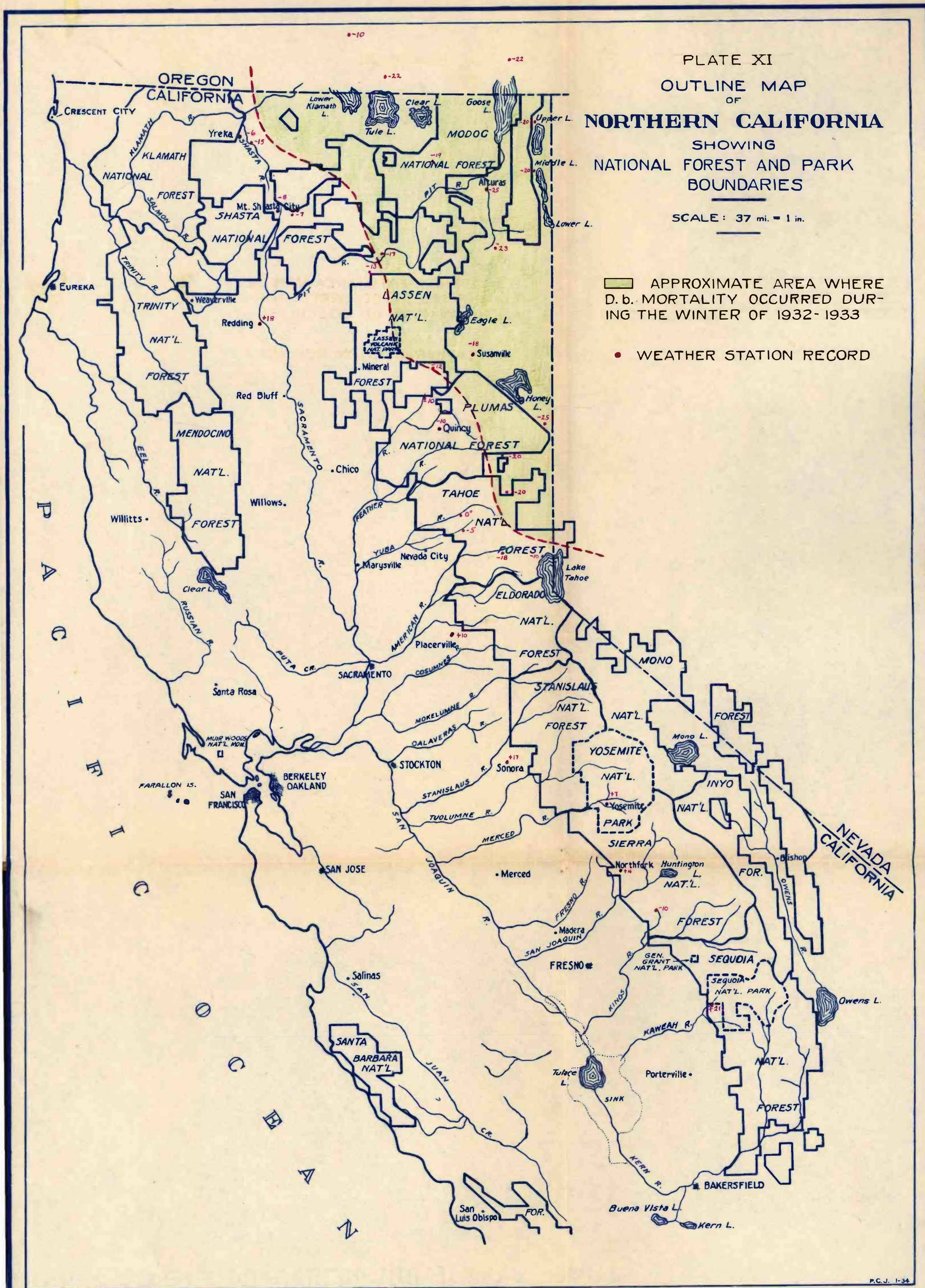


PLATE XI
OUTLINE MAP OF
NORTHERN CALIFORNIA
SHOWING
NATIONAL FOREST AND PARK BOUNDARIES
SCALE: 37 mi. = 1 in.
APPROXIMATE AREA WHERE D. b. MORTALITY OCCURRED DURING THE WINTER OF 1932-1933
WEATHER STATION RECORD
OREGON
CALIFORNIA
NEVADA
CALIFORNIA
PACIFIC OCEAN
CRESCENT CITY
Yreka
KLAMATH NATIONAL FOREST
SHASTA NATIONAL FOREST
Mt. Shasta City
MODOC NATIONAL FOREST
Lower Klamath L.
Tule L.
Clear L.
Goose L.
Upper L.
Middle L.
Lower L.
Alturas
EUREKA
Weaverville
TRINITY NAT'L. FOREST
Redding
LASSEN NAT'L. FOREST
LASSEN VOLCANIC NAT. PARK
Mineral
Eagle L.
Susanville
Honey L.
Red Bluff
PLUMAS NATIONAL FOREST
Quincy
MENDOCINO NAT'L. FOREST
Chico
Willows
Willitts
TAHOE NAT'L. FOREST
Marysville
Nevada City
Lake Tahoe
ELDORADO NAT'L. FOREST
Clear L.
Placerville
SACRAMENTO
Santa Rosa
MONO NAT'L. FOREST
STANISLAUS NAT'L. FOREST
Mono L.
YOSEMITE NAT'L. PARK
Yosemite
MUIR WOODS NAT'L. MON.
STOCKTON
Sonora
FARALLON IS.
SAN FRANCISCO
BERKELEY
OAKLAND
INYO NAT'L. FOR.
SIERRA NAT'L. FOREST
Bishop
SAN JOSE
Merced
Northfork
Huntington L.
Madera
FRESNO
GEN. GRANT NAT'L. PARK
SEQUOIA NAT'L. FOREST
SEQUOIA NAT'L. PARK
Owens L.
Salinas
SANTA BARBARA NAT'L. FOR.
Tulare L.
Porterville
SINK
BAKERSFIELD
Buena Vista L.
Kern L.
San Luis Obispo
KLAMATH R.
SALMON R.
SHASTA R.
PIT R.
TRINITY R.
SACRAMENTO R.
EEL R.
FEATHER R.
YUBA R.
AMERICAN R.
RUSSIAN R.
PUTA CR.
COSUMNES R.
MOKELUMNE R.
CALAVERAS R.
STANISLAUS R.
TUOLUMNE R.
MERCED R.
SAN JOAQUIN R.
FRESNO R.
KINGS R.
KAWEAH R.
KERN R.
OWENS R.
SAN JUAN CR.
SAN
SALINAS
P.C.J. 1-34